EXPRESS MAIL NO. EV253247338US

MICROFEATURE WORKPIECE PROCESSING APPARATUS AND METHODS FOR BATCH DEPOSITION OF MATERIALS ON MICROFEATURE WORKPIECES

TECHNICAL FIELD

[0001] The present invention is related to equipment and methods for processing microfeature workpieces, e.g., semiconductor wafers. Aspects of the invention have particular utility in connection with batch deposition of materials on microfeature workpieces, such as by atomic layer deposition or chemical vapor deposition.

BACKGROUND

[0002] Thin film deposition techniques are widely used in the manufacturing of microfeatures to form a coating on a workpiece that closely conforms to the surface topography. In the context of microelectronic components, for example, the size of the individual components in the devices on a wafer is constantly decreasing, and the number of layers in the devices is increasing. As a result, the density of components and the aspect ratios of depressions (e.g., the ratio of the depth to the size of the opening) are increasing. The size of such wafers is also increasing to provide more real estate for forming more dies (i.e., chips) on a single wafer. Many fabricators are currently transitioning from 200mm to 300mm workpieces, and even larger workpieces will likely be used in the future. Thin film deposition techniques accordingly strive to produce highly uniform conformal layers that cover the sidewalls, bottoms, and corners in deep depressions that have very small openings.

[0003] One widely used thin film deposition technique is chemical vapor deposition (CVD). In a CVD system, one or more precursors that are capable of reacting to form a solid thin film are mixed in a gas or vapor state, and then the

precursor mixture is presented to the surface of the workpiece. The surface of the workpiece catalyzes the reaction between the precursors to form a solid thin film at the workpiece surface. A common way to catalyze the reaction at the surface of the workpiece is to heat the workpiece to a temperature that causes the reaction.

[0004] Although CVD techniques are useful in many applications, they also have several drawbacks. For example, if the precursors are not highly reactive, then a high workpiece temperature is needed to achieve a reasonable deposition rate. Such high temperatures are not typically desirable because heating the workpiece can be detrimental to the structures and other materials already formed on the workpiece. Implanted or doped materials, for example, can migrate within silicon workpieces at higher temperatures. On the other hand, if more reactive precursors are used so that the workpiece temperature can be lower, then reactions may occur prematurely in the gas phase before reaching the intended surface of the workpiece. This is undesirable because the film quality and uniformity may suffer, and also because it limits the types of precursors that can be used.

[0005] Atomic layer deposition (ALD) is another thin film deposition technique. Figures 1A and 1B schematically illustrate the basic operation of ALD processes. Referring to Figure 1A, a layer of gas molecules A coats the surface of a workpiece W. The layer of A molecules is formed by exposing the workpiece W to a precursor gas containing A molecules, and then purging the chamber with a purge gas to remove excess A molecules. This process can form a monolayer of A molecules on the surface of the workpiece W because the A molecules at the surface are held in place during the purge cycle by physical adsorption forces at moderate temperatures or chemisorption forces at higher temperatures. The layer of A molecules is then exposed to another precursor gas containing B molecules. The A molecules react with the B molecules to form an extremely thin layer of solid material C on the workpiece W. The chamber is then purged again with a purge gas to remove excess B molecules.

[0006] Figure 2 illustrates the stages of one cycle for forming a thin solid layer using ALD techniques. A typical cycle includes (a) exposing the workpiece to the first precursor A, (b) purging excess A molecules, (c) exposing the workpiece to the second precursor B, and then (d) purging excess B molecules. The purge process typically comprises introducing a purge gas, which is substantially non-reactive with either precursor, and exhausting the purge gas and excess precursor from the reaction chamber in a pumping step. In actual processing, several cycles are repeated to build a thin film on a workpiece having the desired thickness. For example, each cycle may form a layer having a thickness of approximately 0.5-1.0Å, and thus it takes approximately 60-120 cycles to form a solid layer having a thickness of approximately 60Å.

[0007] One drawback of ALD processing is that it has a relatively low throughput compared to CVD techniques. For example, ALD processing typically takes several seconds to perform each A-purge-B-purge cycle. This results in a total process time of several minutes to form a single thin layer of only 60Å. In contrast to ALD processing, CVD techniques only require about one minute to form a 60Å thick layer. In single-wafer processing chambers, ALD processes can be 500%-2000% longer than corresponding single-wafer CVD processes. The low throughput of existing single-wafer ALD techniques limits the utility of the technology in its current state because ALD may be a bottleneck in the overall manufacturing process.

[0008] One promising solution to increase the throughput of ALD processing is processing a plurality of wafers (e.g., 20-250) simultaneously in a batch process. Figure 3 schematically illustrates a conventional batch ALD reactor 10 having a processing enclosure 20 coupled to a gas supply 30 and a vacuum 40. The processing enclosure 20 generally includes an outer wall 22 and an annular liner 24. A platform 60 seals against the outer wall or some other part of the enclosure 20 via a seal 62 to define a process chamber 25. Gas is introduced from the gas supply 30 to the process chamber 25 by a gas nozzle 32 that introduces gas into the main chamber 28 of the process chamber 25. Under influence of the vacuum

40, the gas introduced via the gas nozzle 32 will flow through the main chamber 28 and outwardly into the annular exhaust 26 to be drawn out with a vacuum 40. A plurality of workpieces W, e.g., semiconductor wafers, may be held in the processing enclosure in a workpiece holder 70. In operation, a heater 50 heats the workpieces W to a desired temperature and the gas supply 30 delivers the first precursor A, the purge gas, and the second precursor B as discussed above in connection with Figure 2.

[0009] However, when depositing material simultaneously on a large number of workpieces in an ALD reactor 10 such as that shown in Figure 3, it can be difficult to uniformly deposit the precursors A and B across the surface of each of the workpieces W. Removing excess precursor from the spaces between the workpieces W can also be problematic. In an ALD reactor such as that shown in Figure 3, the primary mechanism for removing residual precursor that is not chemisorbed on the surface of one of the workpieces is diffusion. This is not only a relatively slow process that significantly reduces the throughput of the reactor 10, but it also may not adequately remove residual precursor. As such, conventional batch ALD reactors may have a low throughput and form non-uniform films.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Figures 1A and 1B are schematic cross-sectional views of stages in ALD processing in accordance with the prior art.

[0011] Figure 2 is a graph illustrating a cycle for forming a layer using ALD techniques in accordance with the prior art.

[0012] Figure 3 is a schematic representation of a system including a reactor for depositing a material onto a microfeature workpiece in accordance with the prior art.

[0013] Figure 4 is an isometric view of a microfeature workpiece holder in accordance with one embodiment of the invention.

[0014] Figure 5 is a side elevation view of the microfeature workpiece holder of Figure 4.

[0015] Figure 6 is a schematic cross-sectional view of the microfeature workpiece holder of Figures 4 and 5 taken along line 6-6 of Figure 5.

[0016] Figure 7 is a schematic cross-sectional view of the microfeature workpiece holder of Figures 4-6 taken along line 7-7 of Figure 6.

[0017] Figure 8 is a schematic cross-sectional view of the microfeature workpiece holder of Figures 4-7 taken along line 8-8 of Figure 6.

[0018] Figure 9 is a schematic side elevation view of a microfeature workpiece holder in accordance with another embodiment of the invention.

[0019] Figure 10 is a schematic isometric view of a microfeature workpiece holder in accordance with yet another embodiment of the invention.

[0020] Figure 11 is a schematic side elevation view of the microfeature workpiece holder of Figure 10.

[0021] Figure 12 is a schematic cross-sectional view of the microfeature workpiece holder of Figures 10 and 11 taken along line 12-12 of Figure 11.

[0022] Figure 13 is a schematic cross-sectional view of a portion of the microfeature workpiece holder of Figures 10-12 taken along line 13-13 of Figure 12.

[0023] Figure 14 is a schematic cross-sectional view of a portion of microfeature workpiece holder of Figures 10-13 taken along line 14-14 of Figure 12.

[0024] Figure 15 is a schematic illustration of a microfeature workpiece processing system in accordance with a further embodiment of the invention.

[0025] Figure 16 is a schematic illustration of a microfeature workpiece processing system in accordance with another embodiment of the invention.

[0026] Figure 17 is a schematic illustration of a microfeature workpiece processing system in accordance with yet another embodiment of the invention.

DETAILED DESCRIPTION

A. Overview

[0027] Various embodiments of the present invention provide microfeature workpiece holders, systems including processing chambers, and methods for depositing materials onto microfeature workpieces. Many specific details of the invention are described below with reference to reactors for depositing materials onto microfeature workpieces. The term "microfeature workpiece" is used throughout to include substrates upon which and/or in which microelectronic devices, micromechanical devices, data storage elements, read/write components, and other devices are fabricated. For example, microfeature workpieces can be semiconductor wafers such as silicon or gallium arsenide wafers, glass substrates, insulative substrates, and many other types of materials. The microfeature workpieces typically have submicron features with dimensions of 0.05 microns or greater. Furthermore, the term "gas" is used throughout to include any form of matter that has no fixed shape and will conform in volume to the space available, which specifically includes vapors (i.e., a gas having a temperature less than the critical temperature so that it may be liquefied or solidified by compression at a constant temperature). Several embodiments in accordance with the invention are set forth in Figures 4-17 and the following text to provide a thorough understanding of particular embodiments of the invention. A person skilled in the art will understand, however, that the invention may have additional embodiments, or that the invention may be practiced without several of the details of the embodiments shown in Figures 4-17.

[0028] Certain embodiments of the invention provide microfeature workpiece holders that are adapted to hold a plurality of microfeature workpieces, e.g., for chemical processing such as ALD. These workpiece holders may include a gas distributor comprising one or more gas delivery conduits. The gas delivery conduit may have an inlet and a plurality of outlets, which may be positioned to

direct a flow of process gas into the spaces between the workpieces. This can facilitate more uniform distribution of reaction precursors on a microfeature workpiece surface, for example. The distribution of these outlets may also facilitate rapid and effective purging of the space between the workpieces.

[0029] Other embodiments of the invention provide microfeature workpiece processing systems that may include an enclosure defining a process chamber, a removable microfeature workpiece holder disposed in the processing chamber, and a process gas supply conduit. The workpiece holder may be similar to the workpiece holders described above and include a gas distributor having outlets adapted to direct a flow of gas from the process gas supply between the microfeature workpieces.

[0030] Other embodiments of the invention provide methods of depositing materials on microfeature workpieces. Although a number of methods are described below, one method having particular utility in connection with ALD includes positioning a microfeature workpiece holder in a process chamber, with the microfeature workpiece holder supporting a plurality of workpieces to define process spaces between each pair of adjacent workpieces. A first precursor gas may be delivered to the process chamber to deposit a quantity of the first precursor gas on a surface of each of the microfeature workpieces. A purge gas may be delivered to the microfeature workpiece holder. The microfeature workpiece holder may carry a gas distributor that delivers a first flow of the purge gas transversely into the space between a pair of workpieces and delivers a second flow of the purge gas transversely into a process space between another pair of workpieces. The method may further include delivering a second precursor gas to the process chamber; the second precursor gas reacts with the quantity of the first precursor gas to form a layer of material on the surfaces of the workpieces.

[0031] For ease of understanding, the following discussion is subdivided into three areas of emphasis. The first section discusses microfeature workpiece holders in accordance with selected embodiments of the invention. The second section

describes aspects of microfeature workpiece processing systems in other embodiments of the invention. The third section discusses outlines methods in accordance with other aspects of the invention.

B. Microfeature Workpiece Holders

[0032] Figures 4-8 schematically illustrate a microfeature workpiece holder 100 in accordance with one embodiment of the invention. This microfeature workpiece holder 100 generally includes a base, a plurality of columns 120, and a cap 150. The particular embodiment shown in Figures 4-8 employs 3 columns, namely columns 120a, 120b and 120c. The base 110 and the cap 150 are each generally semicircular in shape and the columns 120a-c are spaced approximately 90° from one another so that the two outer columns 120a and 120c are generally diametrically opposed to one another. It should be recognized that this is simply one possible embodiment that may be useful in connection with microfeature workpieces that are generally circular in shape. In other embodiments, more or fewer columns 120 may be employed. In addition, the base 110 and/or the cap 150 may take the form of a solid plate or disk or have any other desired shape. In other embodiments, only one of the base 110 or cap 150 is employed. For example, the cap 150 may be omitted and the base 110 may provide the requisite support for the columns 120.

[0033] Each of the columns 120 in the microfeature workpiece holder 100 is generally circular in cross-section. In other embodiments, the columns may have other shapes. For example, the columns 120 may be generally wedge-shaped, such as those suggested in PCT International Publication No. WO 02/095807 entitled, "Silicon Fixtures Useful for High Temperature Wafer Processing," the teachings of which are incorporated herein by reference.

[0034] Each of the columns 120 includes a plurality of workpiece supports spaced longitudinally along its length. In the illustrated embodiment, these workpiece supports comprise slots 122 that extend into the body of the column 120. In other

embodiments, the workpiece holders may comprise inwardly-extending fingers, rings, clamps, or other workpiece-supporting structures known in the art, e.g., supports used in semiconductor wafer handling and processing equipment. Figures 4 and 5 show columns with a limited number of slots 122. Depending on the application in which the workpiece holder 100 is used, the columns 120 may include fewer or more slots.

[0035] The size and shape of the slots 122 can be modified as desired. In one embodiment, each of the slots 122 is adapted to receive an edge portion of one of the microfeature workpieces (as suggested in Figure 5). A single slot 122 may not be deep enough to receive a sufficient portion of a microfeature workpiece W to support the workpiece W. In the illustrated embodiment, the slots 122 on each of the columns 120a-c are positioned relative to one another to cooperatively support the workpieces W. As illustrated in Figure 5, each slot 122 may be generally horizontally aligned with a corresponding one of the slots 122 on each of the other two columns 120. This permits a workpiece W to be supported at three separate peripheral locations to enhance the support of each of the workpieces W. If these slots 122 are spaced the same distance along the length of each of the columns 120, the slots 122 may support a plurality of microfeature workpieces W in a spaced-apart, generally parallel relationship. The spaced-apart relationship of the workpieces W will define a process space S between each of the workpieces W.

[0036] As shown schematically in Figure 5, the microfeature workpiece holder 100 also includes a gas distributor 130. This gas distributor 130 includes at least one gas delivery conduit 134 adapted to direct a flow of process gas relative to the workpieces W. In one embodiment, a single gas delivery conduit 134 is employed. In the particular embodiment shown schematically in Figure 5, the gas distributor 130 includes a manifold 132 connecting a plurality of gas delivery conduits 134a-c. The manifold 132 may comprise an arcuate fluid passageway formed in the arcuate base 110 that provides fluid communication between a gas inlet 140 in the base 110 and each of the gas delivery conduits 134a-c. In the

illustrated embodiment, a separate gas delivery conduit 134 is associated with each of the columns 120. Hence, a first gas delivery conduit 134a is carried by the first column 120a, a second gas delivery conduit 134b is carried by a second column 120b, and a third gas delivery conduit 134c is carried by the third column 120c. In some embodiments, one or more of the columns 120 may not include a gas delivery conduit 134. In other embodiments, more than one gas delivery conduit 134 may be carried by each column 120.

[0037] As best seen in Figures 6-8, the gas delivery conduit 134b may comprise an internal lumen formed in the second column 120b. (Although Figures 6-8 only illustrate the second column 120b, the structure of the other columns 120a and 120c may be substantially the same. Hence, the following discussion generically refers to a column 120 and a gas delivery conduit 134.) The gas delivery conduit 134 includes a plurality of transverse passages 136, each of which directs fluid from the gas delivery conduit 134 to one of a plurality of outlets 138. These outlets 138 are disposed between two adjacent slots 122. The gas delivery conduit 134, including each of the transverse passages 136 is generally circular in cross-section and the outlets 138 define generally circular openings. The size and shape of the gas delivery conduits 134 and outlets 138 in the microfeature workpiece holder 100 can be varied, though. In other embodiments, for example, the outlets 138 may comprise ellipses or slots having a transverse dimension longer than a longitudinal dimension or include a directional nozzle (not shown).

[0038] When the microfeature workpieces W are loaded in the microfeature workpiece holder 100, they will define a series of process spaces S. At least one outlet 138 is desirably associated with each of these process spaces S. In the illustrated embodiment, one outlet 138 is positioned between each pair of adjacent slots 122 on each of the columns 120a-c. As a consequence, three outlets 138 are associated with each process space, with one outlet being associated with each of the columns 120a-c supporting the workpieces W. Directing transverse gas flows into the processing spaces S can further enhance

the flow of process gas from the gas distributor 130 into and through the processing spaces S.

[0039] Referring back to Figure 4, each of the outlets 138 may be directed inwardly toward a central axis A (in Figure 4) of the microfeature workpiece holder 100. Consequently, when the workpieces W are positioned in the holder 100, each of the outlets 138 will be positioned to direct a flow of process gas inwardly toward a center of one of the workpieces W. This is expected to further enhance the uniformity of material deposition and/or decrease the time needed to purge the system.

[0040] The microfeature workpiece holder 100 can be formed of any material that is suitable in light of the microfeature workpieces W with which it will be used and the anticipated conditions of use. If the microfeature workpieces W comprise semiconductor wafers, for example, the microfeature workpiece holder 100 may be formed from glass, fused silica (e.g., fused quartz), or polysilicon (i.e., polycrystalline silicon), among other materials. For other types of applications that may be less sensitive to contamination, the microfeature workpiece holder 100 may be formed of a metal, a ceramic, or a suitably stiff and durable polymeric material.

[0041] Figure 9 schematically illustrates a microfeature workpiece holder 102 in accordance with another embodiment of the invention. This microfeature workpiece holder 102 is similar in many respects to the microfeature workpiece holder 100 shown in Figures 4-8 and like reference numbers are used in Figures 4-9 to illustrate like elements.

[0042] One difference between the microfeature workpiece holders 100 and 102 relates to the design of the gas distributor. The gas distributor 130 shown in Figure 5 employs a single gas inlet 140 that communicates with each of the gas delivery conduits 134a-c through a common manifold 132. The microfeature workpiece holder 102 of Figure 9 does not include a manifold 132. Instead, the gas distributor 131 in Figure 9 has a separate gas inlet 140 for each of the gas delivery conduits 134. Hence, one inlet 140a is in fluid communication with a first

one of the gas delivery conduits 134a, a second gas inlet 140b is in fluid communication with a second gas delivery conduit 134b, and a third gas inlet 140c is in fluid communication with a third gas delivery conduit 134c. In this design, each of the gas delivery conduits 134 may be adapted to delivery a process gas flow that is independent of the process gas flow delivered through each of the other conduits 134. As noted below, this may permit a different process gas to be delivered through each of the conduits 134a-c. In the context of the ALD process outlined above in connection with Figures 1 and 2, for example, one of the gas delivery conduits (e.g., conduit 134a) may be dedicated to delivering the first precursor gas A, a second one of the gas delivery conduits (e.g., conduit 134b) may be used to deliver the second precursor gas B, and the third gas delivery conduit 134c may be used to deliver the purge gas.

[0043] Figures 10-14 schematically illustrate a microfeature workpiece holder 200 in accordance with another embodiment of the invention. This microfeature workpiece holder 200 generally includes a base 210, a cap 250, and at least one column 220 extending between the base 210 and the cap 250. The illustrated embodiment employs three columns 220a-220c that are spaced generally equiangularly in a manner similar to that described above in connection with the microfeature workpiece holder 100 of Figure 4. Each of the columns 220a-c may include a series of longitudinally-spaced slots 222 oriented inwardly toward a central axis A of the microfeature workpiece holder 200. Each of these slots 222 may be adapted to receive an edge portion of a microfeature workpiece W (omitted in Figures 10-14 for ease of understanding). Each of the slots 222 in a particular column 220 may be positioned relative to a corresponding slot 222 in each of the other columns 220 so the three corresponding slots 222 can cooperatively support a microfeature workpiece W.

[0044] One of the differences between the microfeature workpiece holders 100 and 200 of Figures 4-8 and 10-14, respectively, relates to the relationship of the gas distributor to the columns of the workpiece holder. In the workpiece holder 100 of Figures 4-8, the gas distributor 130 includes several gas delivery conduits

134, each of which comprises an internal lumen of one of the columns 120. The microfeature workpiece holder 200 of Figures 10-14, in contrast, has substantially solid columns 220. As suggested in Figures 12 and 14, the columns 220 may have a solid interior with a series of spaced-apart slots 222 formed in an inwardly-oriented surface of the column.

[0045] Referring to Figure 11, the microfeature workpiece holder 200 also includes a gas distributor, generally designated as reference number 230, that includes a series of gas delivery conduits 234. In particular, a first gas delivery conduit 234a is carried with respect to the first column 220a, a second gas delivery conduit 234b is carried with respect to a second column 220b, and a third gas delivery conduit 234c is carried with respect to a third column 220c. The position of each of the gas delivery conduits 234 may be fixed relative to the adjacent column 220 in any desired fashion. In one embodiment, the gas delivery conduits 234 may be supported entirely by the base 210 and/or the cap 250. In the particular embodiments shown in Figures 10 and 11, a base portion 242 of each of the conduits 234 is received within and passes through an opening in the base 210, but the opposite end of the gas delivery conduit 234 is spaced from the cap 250. In another embodiment, each of the conduits 234 is attached to the cap 250, as well. As shown in Figures 11 and 12, each of the gas delivery conduits 234 in the illustrated embodiment is positioned immediately adjacent to one of the columns 220. In such an arrangement, each of the conduits 234 may be attached to or otherwise physically supported by the adjacent column 220. In other embodiments (not shown), the conduits 234 may be attached only to an adjacent column 220 without being directly attached to the base 210 or the cap 250. In still other embodiments, the gas delivery conduits 234 need not be positioned close to any of the columns 220. For example, one gas delivery conduit 234 may be positioned between the first two columns 220a and 220b and a second gas delivery conduit 234 may be positioned between the second and third columns 220b and 220c.

[0046] The gas delivery conduits 234 provide a fluid pathway between a gas inlet 240 and a plurality of gas outlets 238. As illustrated in Figure 13, the gas delivery conduits 234 (in this case, gas delivery conduit 234b) may include a longitudinally extending channel 235 and a series of transverse pathways 236 extending transversely inwardly toward the axis (axis A in Figure 10) of the microfeature workpiece holder 200. The outlets 238 of these pathways 236 may be positioned laterally along the length of the respective conduit 234 so each outlet 238 can direct a flow of process gas intermediate a pair of adjacent slots 222. When the microfeature workpieces W (not shown in Figures 10 and 11) are positioned in the microfeature workpiece holder 200, these outlets 238 would, therefore, direct a flow of process gas into the process space (S in Figure 5) defined between two adjacent microfeature workpieces W.

[0047] The gas distributor 230 of Figures 10-14 includes a separate gas inlet 240 for each of the gas delivery conduits 234. In an alternative embodiment, two or more of the gas delivery conduits 234 may communicate with a common inlet 240 via a manifold (not shown) in the base 210, similar to the manifold 132 in the microfeature workpiece holder 100 discussed above.

C. Microfeature Workpiece Processing Systems

[0048] The microfeature workpiece holders 100, 102, and 200 may be used for a variety of processes. Figures 15-17 schematically illustrate select microfeature workpiece processing systems that employ microfeature workpiece holders to process a batch of microfeature workpieces simultaneously. The microfeature workpiece holders employed in these processing systems may, in select embodiments, employ features of the microfeature workpiece holders 100, 102, and/or 200 described above.

[0049] Figure 15 schematically illustrates a microfeature workpiece processing system 300 in accordance with one embodiment of the invention. This system 300 includes a reactor 310 adapted to receive a plurality of microfeature

workpieces W in a holder. In the specific embodiment shown in Figure 15, the workpieces W are carried in a workpiece holder 100 substantially as described above in connection with Figures 4-8.

[0050] The reactor 310 generally includes an enclosure 320 defined by a wall 322 and a holder-supporting platform 326. The wall 322 may sealingly engage the platform 326, illustrated schematically in Figure 15 as an O-ring seal 324. This will define a process chamber 325 within which the microfeature workpiece holder 100 may be received. The reactor 310 may also include a heater 330 and a vacuum 340 that communicates with the process chamber 325 by a vacuum line 342. The heater 330 may be of any conventional design, e.g., an inductance heater or the like.

[0051] A gas supply system 350 of the reactor 310 generally includes a plurality of individual gas supplies 352, with at least one gas supply 352 provided for each of the process gases used in processing workpieces W in the system 300. The illustrated embodiment includes a first gas supply 352a to deliver a first gas (GAS_1), a second gas supply 352b adapted to deliver a second gas (GAS_2), and a third gas supply 352c adapted to deliver a third gas (GAS_3). In the context of ALD such as that discussed above in connection with Figures 1 and 2, the first gas supply 352a may provide a supply of the first precursor A, the second gas supply 352b may provide a supply of the second precursor B, and the third gas supply 352c may provide a supply of the purge gas. Each of the individual gas supplies 352a-c may be provided with an individual gas supply line 356a-c, respectively. These individual supply lines 356a-c are coupled to a primary gas supply line 356. In the illustrated embodiment, each of the individual gas supply lines 356a-c is provided with a selectively controllable secondary valve 354a-c, respectively. These secondary valves may be used to control the flow rate of the gas from each of the individual gas supply 352 into the main gas supply line 356, hence regulating the composition and flow rate of gas to the gas supply line 356.

[0052] The gas distributor 130 of the holder 100 may be coupled to the gas supply system 350 in a variety of manners. In the schematic illustration of Figure 15, a

gas fitting 360 in the platform 326 may be releasably coupled to the gas inlet 140 of the holder 100. This fitting 360 is coupled to the remainder of the gas supply 350 by a supply line 356.

[0053] The flow of gas through the supply line 356 to the gas distributor 130 of the holder 100 may be controlled, at least in part, by a main valve 362 that is under the control of a controller 370. The controller 370 may take any of a variety of forms. In one embodiment, the controller 30 comprises a computer having a programmable processor programmed to control operation of the system 300 to deposit material on the workpieces W. The controller 370 may also be operatively coupled to the secondary valves 354a-c to control the composition of the gas delivered to the main valve 362 via the supply line 356. The controller 370 may also be coupled to the vacuum 340 (as illustrated) or any other component of the processing system 300, e.g., the heater 330.

[0054] Figure 16 schematically illustrates a microfeature workpiece processing system 302 in accordance with an alternative embodiment of the invention. This processing system 302 is similar in many respects to the processing system 300 of Figure 15 and like reference numbers are used in Figures 15 and 16 to indicate like elements. The processing system 300 uses the microfeature workpiece holder 100 of Figures 4-8. The workpieces W in processing system 302 of Figure 16 are instead held in the microfeature workpiece holder 102 of Figure 9. As noted above, the gas distributor 131 of this holder 102 has a series of independent gas delivery conduits 134, each of which has a separate gas inlet 140.

[0055] The gas supply 351 of Figure 16 is similar in many respects to the gas supply 350 of Figure 15. In Figure 15, each of the individual gas supply lines 356a-c were joined into a main supply line 356 for delivery to a single gas fitting 360. In the gas supply 351 of Figure 16, however, each of the individual gas supplies 352a-c is independently coupled to a separate gas fitting 360a-c, respectively. In particular, a first gas fitting 360a may releasably couple the first gas supply line 356a to the first inlet 140a, a second gas fitting 360b may

releasably couple a second gas supply line 356b to the second gas inlet 140b, and a third gas fitting 360c may releasably couple a third gas supply line 356c to the third gas inlet 140c. The flow of gas from each of the gas supplies 352a-c may be independently controlled by a separate valve 354a-c through a common controller 370. Introducing each of the process gases through an independent, dedicated gas delivery conduit 134 can avoid the need to purge the gas delivery conduit 134 after delivering one precursor and before delivering another precursor. This may be advantageous in CVD applications because it permits the precursor gases to be introduced separately into the process chamber 325, more effectively restricting the deposition of the reactant to the vicinity of the workpieces W.

[0056] Figure 17 illustrates a microfeature workpiece processing system 400 in accordance with still another embodiment of the invention. This processing system 400 generally includes a reactor 410 having a processing enclosure 420 within which a workpiece holder (e.g., workpiece holder 100 of Figures 4-8) carrying one or more workpieces W may be received. The processing enclosure 420 is generally defined by an outer wall 422 and a platform 426 adapted to carry the workpiece holder 100. This processing enclosure 420 also includes a liner 424 that functionally divides the process chamber 425 into a main chamber 427 and a generally annular exhaust 428 coupled to the vacuum 440 by a vacuum line 442. The reactor 410 may also include a heater 430.

[0057] The processing system 400 may include a first gas supply system 450 and a second gas supply system 460. The first gas supply system 450 includes a plurality of individual gas supplies 452a-c, each of which may include a separate process gas. Hence, the first gas supply 452a may include a precursor gas A (GAS_1) and a second gas supply 452b may provide a supply of a second precursor gas B (GAS_2). Optionally, the first gas supply system 450 may also include a supply of a purge gas (GAS_3) in a third gas supply. Each of these individual gas supplies 452a-c may be coupled to a common gas supply line 456. A separate valve 454a, 454b, or 454c may be operated by a controller 470 to

control the flow of gas from the individual gas supplies 452a, 452b, and 452c, respectively.

[0058] The gas supply line 456 of the first gas supply system 450 may be in fluid communication with one or more gas supply nozzles 458. The gas supply nozzle 458 may be adapted to deliver a flow of process gas to the main chamber 427 outside the process spaces S of the process chamber 425. This gas may flow generally longitudinally through the main chamber 427 then out of the process chamber 425 via the annular exhaust 428. This gas supply system 450 is, in some respects, analogous to the gas supply 30 and gas nozzle 32 illustrated in Figure 3.

[0059] The microfeature workpiece processing system 400 also includes a second gas supply system 460. This gas supply system 460 may be adapted to deliver one or more process gases to the process chamber 425 via the gas distributor 130 of the workpiece holder 100. Gas will exit the outlets 138 of the gas distributor 130 in a direction transverse to the longitudinally directed flow from the nozzle 458. In the specific embodiment shown in Figure 17, the second gas supply system 460 includes a single individual gas supply 462 containing a purge gas (GAS_3). The individual gas supply 462 is coupled to a gas fitting 468 in the platform 426 by a valve 464 operatively linked to the controller 470. The gas fitting 468 is adapted to be releasably coupled to the inlet 140 of the gas distributor 130. Although the second gas supply system 460 shown in Figure 16 only provides a supply of a single purge gas, this gas supply system 460 may include two or more individual gas supplies 462 to provide a variety of different process gas compositions to the gas distributor 130.

D. Methods of Depositing Materials On Microfeature Workpieces

[0060] As noted above, other embodiments of the invention provide methods of processing microfeature workpieces. In the following discussion, reference is made to the particular microfeature workpiece processing systems 300, 302, and

400 shown in Figures 15-17. It should be understood, though, that reference to these particular processing systems and the workpiece holders used therein is solely for purposes of illustration and that the methods outlined below are not limited to any particular workpiece holder or processing system shown in the drawings or discussed in detail above. In addition, the following discussion focuses primarily on ALD and also touches on possible CVD applications. It should be recognized that the processes outlined below should not be limited to these specific deposition processes. Indeed, aspects of the methods outlined below may have utility in applications in which a process other than material deposition, e.g., selective etching, may be carried out.

[0061] In accordance with one embodiment, a method of processing microfeature workpieces may include positioning a microfeature workpiece holder 100 in a process chamber 325 (using the processing system 300 as an example). The workpiece holder 100 may support a plurality of workpieces W in a spaced-apart relationship to define a process space S between each pair of adjacent workpieces W. The microfeature workpiece holder 100 may be positioned in the process chamber by placing the holder 100 on a platform 326. In one embodiment, the gas fitting 360 may be coupled to the gas inlet 140 of the gas distributor 130 at this time. Once the holder 100 is in place on the platform 326, the platform 326 may be moved toward the wall 322 until the seals 324 substantially seal the enclosure 320 to define the process chamber 325.

[0062] This embodiment also includes delivering at least a first process gas and a second process gas to the process chamber 325. In one embodiment, the first process gas, e.g., a first precursor A, may be delivered to the process chamber 325 by opening the first regulator valve 354a and the main valve 362. This will allow the first gas to flow into the gas distributor 130 and outwardly into the process chamber 325 via the outlets 138. As noted above, these outlets 138 will deliver a flow of the process gas transversely into the process spaces S between the workpieces W.

[0063] The second process gas may be delivered to the process chamber 325 either simultaneously with delivery of the first process gas (e.g., for CVD) or at a different time. If the processing system 300 of Figure 15 is used to deposit a material via ALD, for example, a flow of the first precursor gas A from the first supply 352a may be terminated by closing the valve 354a. A flow of purge gas from the third gas supply 352c may be delivered into the process spaces S by opening the associated regulator valve 154c. The regulator valve 154c may be closed and a flow of the second precursor gas B from the second gas supply 352b may then be introduced via the nozzles 138. By appropriate control of the valves 354 and 362 and the vacuum 340, the controller 370 may be used to deposit a reaction product via an ALD process such as that discussed above in connection with Figures 1 and 2.

[0064] Delivering process gases transversely into the process space S between the workpieces W via the outlets 138 can fairly rapidly change the gas present in the process space S. In the conventional system of Figure 3, one of the primary mechanisms for gas exchange in the spaces between the workpieces W is diffusion. Delivering a transverse flow of gas in accordance with embodiments of the present invention can deliver a more uniform application of the precursors to be chemisorbed or reacted on the surface of the workpiece W. Delivering the purge gas through the outlets 138 will also provide a more active scrubbing of the gas in the process spaces S, helping clear the process spaces S of any excess precursor gas fairly quickly. This can materially speed up the purge phases of the process illustrated in Figure 2.

[0065] The processing system 300 of Figure 15 introduces process gases through a single inlet 140 and the gas distributor 130 of the workpiece holder 100. The processing system 302 of Figure 16 allows each of the process gases (gas_{1-3}) to be introduced into the process chamber 325 through a separate gas delivery conduit 134a, 134b, or 134c. This can be particularly useful in both ALD and CVD applications. By separating the pathways for delivery of the reaction precursors into separate conduits 134, less care need be taken to purge the gas

delivery system of the first precursor before introducing a second precursor through the same gas delivery system. In the context of CVD, the gas can be introduced separately and allowed to mix in the process space S and react in the immediate vicinity of the workpiece W. This may facilitate use of more highly reactive precursors, which may be problematic if the precursors are introduced together through a common gas delivery path.

[0066] In another specific embodiment, one of the process gases may be introduced through the gas distributor 130 of the workpiece holder 100, but the second process gas may be delivered through a delivery conduit independent of the gas distributor 130. In the context of the microfeature workpiece processing system 400 of Figure 17, for example, the precursor gases may be introduced from separate individual gas supplies 452a and 452b through the gas delivery nozzle 458. This will deliver the precursors to the process spaces S between the workpieces W in a fashion analogous to that in the ALD reactor 10 of Figure 3. In the purge stages illustrated in Figure 2, though, the purge gas (gas_3) may be introduced through the gas distributor 130 either in addition to or instead of introducing the purge gas through the nozzle 458. Delivering the purge gas through the outlets 138 of the workpiece holder gas distributor 130 will help positively scrub the processing spaces S, fairly rapidly sweeping away any excess precursor.

[0067] Unless the context clearly requires otherwise, throughout the description and the claims, the words "comprise," "comprising," and the like are to be construed in an inclusive sense as opposed to an exclusive or exhaustive sense, that is to say, in a sense of "including, but not limited to." Words using the singular or plural number also include the plural or singular number, respectively. When the claims use the word "or" in reference to a list of two or more items, that word covers all of the following interpretations of the word: any of the items in the list, all of the items in the list, and any combination of the items in the list.

[0068] The above-detailed descriptions of embodiments of the invention are not intended to be exhaustive or to limit the invention to the precise form disclosed

above. While specific embodiments of, and examples for, the invention are described above for illustrative purposes, various equivalent modifications are possible within the scope of the invention, as those skilled in the relevant art will recognize. For example, whereas steps are presented in a given order, alternative embodiments may perform steps in a different order. The various embodiments described herein can be combined to provide further embodiments.

[0069] In general, the terms used in the following claims should not be construed to limit the invention to the specific embodiments disclosed in the specification, unless the above-detailed description explicitly defines such terms. While certain aspects of the invention are presented below in certain claim forms, the inventors contemplate the various aspects of the invention in any number of claim forms. Accordingly, the inventors reserve the right to add additional claims after filing the application to pursue such additional claim forms for other aspects of the invention.